



**Europäisches Patentamt**  
**European Patent Office**  
**Office européen des brevets**



⑪ Publication number: **0 282 251 B1**

## EUROPEAN PATENT SPECIFICATION

④5 Date of publication of patent specification: 17.02.93 ⑤1 Int. Cl.<sup>5</sup>: G01N 9/00, G01N 11/16

②<sup>1</sup> Application number: 88301957.2

② Date of filing: 07.03.88

⑤④ **Fluid transducer.**

③ Priority: 11.03.87 GB 8705757

④3 Date of publication of application:  
14.09.88 Bulletin 88/37

④5 Publication of the grant of the patent:  
17.02.93 Bulletin 93/07

**ⓑ Designated Contracting States:**  
**AT BE CH DE FR IT LI NL SE**

⑤ References cited:  
GB-A- 2 131 952

**THE MARCONI REVIEW**, vol. XLIII, no. 218, 1980, pages 156-175, Rugby, GB; R.M. LANGDON: "Vibratory process control transducers"

**IEEE TRANSACTIONS ON INSTRUMENTATION AND MEASUREMENT**, vol. IM-32, no. 3, September 1983, pages 434-437, IEEE, New York, US; E. STEMME et al.: "Measuring liquid density with a tuning-fork transducer"

**I.S.A. TRANSACTIONS, vol. 20, no. 3, 1981,  
pages 67-75, Research Triangle Park, NC, US;  
B.W. BALLS: "A new on-line density meter  
for viscous liquids and slurries"**

**73** Proprietor: **SCHLUMBERGER INDUSTRIES LIMITED**  
124 Victoria Road  
Farnborough Hampshire, GU14 7PW(GB)

**(72) Inventor: Rudkin, Mark Jonathan**  
**10 Delph Road**  
**Wimborne Dorset(GB)**  
**Inventor: Atkinson, David Ian Heaton**  
**6 Dollis Drive**  
**Farnham Surrey(GB)**

**74 Representative: Stooles, Brian David et al  
Schlumberger Electronics (U.K.) Limited 124  
Victoria Road  
Farnborough Hampshire GU14 7PW (GB)**

**Note:** Within nine months from the publication of the mention of the grant of the European patent, any person may give notice to the European Patent Office of opposition to the European patent granted. Notice of opposition shall be filed in a written reasoned statement. It shall not be deemed to have been filed until the opposition fee has been paid (Art. 99(1) European patent convention).

## Description

This invention relates to fluid transducers, and in particular to fluid transducers having a vibrating element sensor.

Such sensors measure parameters such as density and pressure by allowing them to influence a vibrating element and hence change its resonant frequency. This element is usually a tube resonating in a beam mode, or a cylinder resonating in a hoop mode. In all cases the vibration is monitored by sensing displacement or strain or a time derivative thereof and a drive system supplies an excitation force. Resonance in the chosen mode of vibration is maintained by closing the loop with a suitable feedback amplifier between the pick-up and drive. This amplifies the pick-up signal and applies it to the drive system with the correct phase.

The resonant frequency of the vibrating element may be mass loaded by the density of the fluid. The element appears to have increased its mass by an amount determined by the volume of the entrained fluid and so the resonant frequency is uniquely related to the density.

Descriptions of transducers which operate in accordance with these principles are to be found in United Kingdom Patent Specifications GB 1,264,317, GB 1,175,586 and GB 2,062,865.

An important application of transducers of this type is in the measurement of fluid parameters, for example in liquid flowing in a pipe line. It is therefore desirable that such transducers should disrupt flow as little as possible. Where the entire flow can be conveniently passed through a single tube transducer, little flow disruption occurs. Unfortunately the dimensions of a practical transducer are seldom large enough to accommodate all the flow without intolerable pressure drop, and so there is often recourse to complex and undesirable flow dividers so that part of the flow may be diverted to a sampling transducer or the flow fully metered by a plurality of parallel transducers.

It is a known objective in the transducer art to provide a transducer that can meter a fluid with low flow disruption. Immersion transducers (that is transducers which are introduced into a body of fluid) are practical with vibrating cylinder sensors, but even these often cause unacceptable flow disruption, given the need for support of the element and its closely proximate excitation and pick up means, which result in a structure often much bulkier than the vibrating tube itself.

Another known form of immersion transducer is disclosed in pages 156 to 175 of "The Marconi Review", Vol XLIII, No. 218, 1980, and comprises a tuning fork which is resonantly vibrated while immersed in the fluid to be metered by means of exciting means attached to the tines of the tuning

fork. It is an object of the present invention to provide an transducer of this general kind with an alternative mounting of the exciting means.

According to the present invention, there is provided a fluid transducer comprising:

a sensing element adapted for immersion in a fluid, said sensing element comprising a pair of tines which extend in an axial direction from and are coupled together by a common yoke and which are resonantly vibratable at a common frequency but in antiphase;

piezoelectric means mounted within the sensing element for exciting such resonant antiphase vibration of the tines; and

further piezoelectric means mounted within the sensing element for sensing the frequency of the vibration;

characterised in that the exciting means is mounted under axial compression in a cavity in the yoke in a region thereof closely adjacent the point where the inner face of one of the tines joins the yoke.

Preferably the exciting means is arranged to provide continuous excitation.

A fluid transducer in accordance with the present invention may be arranged as a densitometer by tine shaping to promote density sensitivity, preferably with a re-entrant surface such as a C-section or by means of a cavity adjacent a tine tip section.

In order that features and advantages of the present invention may be further appreciated, examples useful for understanding the invention, and embodiments of the invention will now be described, by way of example only, with reference to the accompanying diagrammatic drawings, of which:-

Figure 1 is a part-sectional view of a fluid densitometer of the kind to which the present invention relates;

Figure 2 is a sectional view of tines forming part of the densitometer of Figure 1;

Figure 3 shows a construction schematic of the transducer of Figure 1;

Figure 4 shows a transducer of the kind to which the present invention relates adapted for installation in a pipe;

Figure 5 shows electronics associated with the transducer of Figure 4;

Figure 6 shows somewhat schematically an alternative mounting arrangement for the transducer of Figure 4;

Figure 7 is a sectional view of fork tines of a viscometer in accordance with the present invention; and

Figures 8 and 9 illustrate, again somewhat schematically, two alternative embodiments of sensing elements for fluid transducers in accordance

with the present invention.

In a fluid transducer 10 (Fig 1), a fork sensing element comprises a yoke portion 11 and two vibratable tines 12, 14 extending therefrom in a substantially parallel relationship. Yoke portion 11 in addition to forming the fork base also serves provide support for the tines by connection to a support flange 15: connection is through the agency of a bellows 16, which provides vibration isolation of the fork with respect to the support flange 15.

Tine 14 has a cavity 17 formed in a root section thereof, to an inside surface of which a piezo-electric ceramic element 18 is affixed by bonding. Yoke 11, bellows 16 and support flange 15 have internal cavities (not shown in detail) so that a cluster of wires 19 may be provided internally, one pair of which are connected to the piezo-electric element 18, which may therefore be electrically excited to thereby excite vibration in the fork structure. A second piezo-electric element 20 is bonded on an adjacent surface of the cavity 17 and by means of electrical connection to this element a signal may be obtained which is representative of the vibration of the tine 14. Tine 12 has a cavity 102 in which two piezo-electric elements are similarly mounted to provide excitation and pick-up signals with respect to tine 12.

In operation, the transducer is arranged such that the tines are fully immersed in fluid to be metered. Vibration is excited by energising the two excitation piezo-electric elements, one within each tine, and the two pick-up piezo-electric elements, again one within each tine, yield a signal representative of the vibratory behaviour of the fork structure. The excitation of the tines is arranged such that the tine vibration is in opposed fundamental cantilever mode. This has the advantage that the vibration is balanced with no motion of the centre of mass of the structure. Conversely enforced motion of the centre mass, for example by external vibration has minimal effect on the vibration performance of the fork.

As the tines move, some of the surrounding liquid is displaced. The effective mass of the tines is increased by an amount determined by the volume of fluid entrained by the moving section; thus the effect is related to fluid density, and a densitometer is provided. Responsiveness to density change is greater as the amount of entrained fluid increases relative to the mass of the tines. To this end the tines 12 and 14 are of C section (Fig 2) having re-entrant facing surfaces 21, 22 which serve both to increase the fluid entraining surface area and to reduce the sectional volume so that the tine carries more fluid with it, thereby increasing density sensitivity. Tines of other section such as 'D' section or simple bars may be employed, but

sections with re-entrant surface are preferred. Where other sections are employed, the mass of moved fluid to tine mass ratio may be improved by making cavities, either closed or open, in the tine tip section.

An optional shroud 103 surrounds the fork element 10. Where shroud 103 is fitted, an extended support flange 104 is used. Shroud 103 is arranged such that it does not resonate over the frequency range of interest and may be for example of wire mesh construction to provide protection for the fork structure without disrupting flow too severely. Such protection may be important where foreign bodies within a metered fluid are likely to impact the tines.

Before the transducer of the embodiment described can be successfully used operationally, calibration will be required. Production transducers will normally be calibrated in at least one known liquid and in a sufficient volume thereof for substantially unbounded conditions to apply. In use, however, boundaries and barriers proximate the fork structure may be unavoidable, and the calibration will be invalid, since surfaces in the metered fluid near the transducer effectively increase the fluid added mass.

A transducer with an alternative form of shroud 103 provides a solution to the problem. Shroud 103 may be made by forming an essentially solid cylinder around the fork structure, the shroud 103 being rigidly attached to the support flange 104. An orifice 105 allows ingress and egress of the fluid to be metered. This form of shroud serves to define a known and repeatable boundary, and the fork transducer with its shroud may therefore be calibrated together, the calibration remaining valid even in the presence of boundaries proximate the region of metering.

Vibrating element transducers have a temperature characteristic dependent upon the Young's modulus variation of the material used with temperature and its thermal expansion. For a practical transducer, calibration against temperature is advantageous to compensate for temperature effects. To this end tuning fork transducer 10 has a cavity 106a containing an internally mounted temperature sensor 106, to which electrical connection is made via wires in cluster 19.

The transducer 10 may be relatively straightforwardly constructed. For metering of oil, for example, the fork structure 10 may be machined from a cylinder 30 (fig 3) of metal 100mm in length and 35mm in diameter. Firstly outer surface portion 36 may be milled away to define the outer tine surface and yoke portion 15. A slot 31 may then be formed extending to a depth which determines the eventual length of the tines and across a diameter of the perforated end face (Fig 3 (c), which represents a plan view of an end face of the cylinder 30). Slot

31 serves to establish separation between the tines.

A hole 32 may be drilled in the slotted end face and further holes 33, 34 and 35 may be drilled in the opposing face (Fig 3 (a), which represents a plan view of the opposite end face of the cylinder 130). Holes 33 and 35, which extend to a depth overlapping slot 31, serve to establish cavities in the tine root sections for later introduction of the piezo-electric elements. Holes 33 and 35 are drilled to a larger bore (39, 300 respectively) effectively extending the tine root cavities at larger diameter. Hole 34 is adapted to receive a temperature sensor. Hole 32 serves to define a reentrant surface on the eventual tines, which will thereby be of 'D' section. Preferably hole 32 extends for the full length of the tines.

Piezo electric elements may now be bonded into position in holes 33 and 35 and a temperature sensor into hole 34, as may be appreciated from equivalent cavities 17, 102 and 106a (Fig 1). Advantageously, holes 34 and 35 may be of more complex slotted shape 37, 38 (shown in outline in Fig 3) to provide opposing flat surfaces in each cavity to which the piezo-electric elements may be bonded. Such more complex shapes may be formed by a process of spark erosion for the case of a metal fork.

Bellows 16 is formed as a thin walled cylinder, resilience being provided by virtue of two folded portions 107, 108. Bellows 16 is welded to yoke portion 11 of transducer 10 around a mating circumference 109.

Support plate 15 (104, with the shroud) may be of any convenient shape and for example adapted to enter and seal with a tapping in a fluid pipe by virtue of threaded portion 110 and 'O' ring 111. Bellows 16 is welded thereto around a circumference 112. Shroud 103 (if fitted) is also welded. A cavity in support plate 15, the hollowness of bellows 16 and the extension of tine root cavities 17 and 102 provide an internal hollow which acts as a path for the placement of wires relaying electrical signals. The exit of wire cluster 19 may be sealed and the hollow filled with a known and inert gas, preventing internal corrosion and condensation of water, for example. Alternatively, the hollow may be evacuated.

The characteristic of the transducer 10 which is exploited if the transducer is used for example as a fluid density transducer is that of change of resonant vibration frequency with change of density of entrained fluid. In order to measure the frequency, several alternatives may be employed, one of which will now be described by way of example.

Vibration is excited by applying voltage to a piezo-electric device mounted at a point of high strain (when vibration is occurring) on a tine and

removed from the natural axis, for example piezo element 18. Voltage application causes the piezo to apply and relax strain to the tine root by virtue of its contraction and bonding, which in turn excites vibration. Conversely, a piezo-electrical element bonded to a structure at a point of changing strain will generate a signal representative of strain variation which may be recovered. Thus once vibration has been established by driving the piezo-electric element, the drive could be removed and a signal recovered representative of the ensuing vibration. Alternatively a first piezo-electric element may be used to excite vibration, and a second used to recover the vibration signal. Similarly either a single element, or a separate drive element and a separate pick up element may be placed one in each tine. As an alternative to intermittent excitation, continuous excitation with either one or two elements and either one or two pick-ups may be employed.

The fluid density transducer of Figure 4 is indicated at 40, and is subjected to continuous excitation by piezo-electric driver elements 41 and 42, mounted on outer surfaces in cavities in tines 43 and 44 respectively. Electrical connections, such as connection 45 of piezo-electric element 41 are established to an electronics board 46 contained within a housing 47. The connections are referenced as a to j. A function of the electronics board is to provide an excitation signal to elements 41 and 42 and accordingly these elements are connected in parallel and driven by a maintaining amplifier 50 (Fig. 5). The input signal for amplifier 50 is derived from piezo-electric pick-ups 47 and 48 respectively mounted in the cavities of tines 43 and 44. Signals from pick-ups 47 and 48 are connected respectively to the non-inverting and inverting input of a dual-input difference amplifier 51. It will be noted that since signals from the pick-ups are connected in opposing sense to inputs of opposite polarity, common mode noise will be rejected. The output of amplifier 51 is connected via a phasing circuit 52 to the input of the maintaining amplifier 50 to establish feedback between the excited and sensed vibration. The transducer 40 is thus maintained in continuous vibration. Phasing circuit 52 in the feed back path serves to ensure that the correct mode of vibration is sustained, as will be described in more detail below.

The output of input difference amplifier 51 is a periodic signal, representative of the frequency of vibration of the fluid transducer element. As previously described, the output is dependent upon temperature, and hence the signal is corrected for temperature by adding an offset 53 in response to a signal from a temperature sensor 400. The degree of correction applied is individually calibrated for each transducer. The corrected signal is re-

laid as an output signal k, for example via an external electrical connector 49. This signal (i.e. between k and l) is thereby representative of the density of fluid by which the transducer is surrounded. Alternatively, an uncorrected signal may be output for relaying to external computation means storing correction and calibration values.

The feedback path via the input amplifier 51, phasing circuit 52 and maintaining amplifier 50 is arranged such that each tine 47, 48 of the transducer vibrates in its fundamental cantilever mode in a balanced way. The use of two drive elements and two pick-up eases the problem of ensuring that the element reliably enters the correct balanced mode of vibration. It has been found that this may be achieved by adjustment of the phasing circuit 52. The phasing circuit may also be adjusted to promote other vibration modes if required.

From the foregoing a number of advantages of the transducers 10 and 40 will be appreciated.

Since the transducers present a solid surface to the fluid to be measured, problems of contamination of the interior and potentially unreliable sealing arrangements for the electronics board are avoided. Furthermore, this solidity removes any dependence upon pressure of the fluid to be metered; which dependence is a characteristic of transducers of the hollow tube and cylinder type, where there are pressure effects due to internal and external pressure difference. Installation of the transducer is straightforward, being for example through a pipe or tank wall. Transducer 40 is adapted to be mounted in a wall 401 of a pipe by a securing flange 402. In some applications vibration isolation will not be required, and transducer 40 is directly welded to flange 402 offering a straightforward and highly secure construction.

Where foreign body impact or proximate surfaces are expected, an optional shroud may be fitted of appropriate type, as already described. Another circumstance where a shroud is of benefit is in intrinsically safe transducers, where the prevention of impact ensures that no large tine excursions can cause large and potentially dangerous voltages to be generated by the high impedance piezo-elements. Such a shrouded calibrated transducer may be adapted for use as a portable fluid meter, which may be used essentially as a dipstick since the structure is substantially insensitive to vibration that might be induced by hand held operation, by virtue of its balanced vibration.

A particular advantage of employing two pick-up elements is that the sensed signals may be connected so as to provide rejection of any common mode signals appearing during transmission.

A further important advantage of the transducers 10 and 40 is the small section presented to flowing fluids. For example, the section presented

by the transducer 40 to fluid flowing in pipe 401 in a direction 403 is only that of a single tine, which for oil might be typically  $70 \times 2.5 \text{ mm}^2$ , as compared with an overall pipe cross sectional area of  $80500 \text{ mm}^2$ , leading to very little flow disturbance. A fork structure with tines of these dimensions formed in metal has a free air resonance at a frequency in the region of 1KHz.

It will be appreciated that by mounting the fork structure turned through  $90^\circ$ , a yet smaller disruptive section may be presented. A preferred alternative when flow in a narrow base pipe 60 (approximately 50mm diameter) is to be metered is mounting fork structure 61 in an elbow section 62 (Figure 6). It will be realised that thereby a tine length which exceeds pipe diameter may be accommodated. The introduction of the fork structure into the flow path causes little significant extra pressure drop over and above that already caused by the elbow. An advantage is that elbow sections are often fitted with inspection plates for probe insertion, to which the transducer flange 63 may be readily adapted.

As the tines vibrate in a liquid, the tines drag through the fluid in shear. Vibration is therefore dependent upon the resistance to shear of the fluid, and hence its viscosity. Generally the tines of a densitometer may be designed to minimise viscosity effects by maximising entrained fluid volume with respect to drag, as in the 'C' section and hollow tines described above. As in many applications, metering over a small viscosity range only is required (e.g. typically  $\pm 10 \text{ Cp}$  for oil), viscosity effects will be negligible. However, where larger viscosity variation is expected, extra corrections and calibrations may be advantageous.

The phase difference between the excitation signal and pick up signal generally increases with viscosity, hence by arranging that phasing circuit 52 acts to maintain a constant phase, viscosity sensitivity is reduced. Two modes of vibration, each exhibiting different density/frequency and viscosity/frequency characteristics may be excited, yielding simultaneous system equations from which viscosity may be eliminated. A detailed description of a two mode approach is to be found in the description of co-pending United Kingdom Patent Application 86 24339 (Publication No. 2182439). An alternative correction approach is to measure the amplitude of the vibration, which varies with viscosity as the Q of the system changes, as more damping is present with highly viscous liquids. Such correction has to be individually calibrated for each transducer.

A yet further possibility is to employ two transducers each exhibiting different density/frequency and viscosity/frequency characteristics.

In an alternative form of the present invention, tine section may be arranged to enhance viscosity sensitivity, thereby providing a liquid viscometer. Tine sections entraining a reduced volume but having a large surface area for drag are therefore advantageous. Tines 60 and 61 (Fig. 7) entrain little liquid, but are affected by drag (and hence viscosity) when vibrated in their plane of elongation. It will be appreciated, therefore, that a transducer having tines of such a section may provide a liquid viscometer analogous to the fluid desitometer described above.

In the transducers described thus far, the piezoelectric exciting and sensing elements have been mounted in the tines. To modify these transducers in accordance with the present invention, at least the exciting elements are mounted in the yoke, as shown in Figures 8 and 9.

Thus in the transducer of Figure 8, a cylindrical cavity 831 is formed in yoke 836, and an annular piezo-electric element 830 is mounted under a predetermined amount of compression in the cavity so as to be coaxially therewith: this can be achieved by making the yoke in two separate pieces which are welded together to entrap the piezo-electric element. The piezo-electric element 830 is insulated from the walls of its cavity 831, and it is symmetrically positioned in the cavity with respect to tines 834, 835. The diameter of the element 830 is such that it passes through the regions of the cavity 831 closely adjacent the high-stress regions of yoke 836 where the inner faces 832, 833 of tines 834, 835 meet the yoke.

When an alternating voltage is applied to the element 830, it alternately tries to expand and contract in a vertical direction (as viewed in Figure 8), so tending to flex the lower surface of the yoke 836 and thus flex tines 834, 835 inwardly and outwardly, ie causing them to vibrate in anti-phase.

Finally, in the transducer of Figure 9, respective plate-like piezo-electrical exciting elements 840, 841 are provided in yoke 842 adjacent the high stress regions where the inner faces 843, 844 of tines 845, 846 meet the yoke. The elements 840, 841 are disposed in respective cavities drilled into yoke 842 from the top, and are held under a predetermined amount of compression by respective plugs 847, 848 screwed into these cavities from the top of yoke 842. Applying an alternating voltage to elements 840, 841 again causes tines 845, 846 to vibrate in anti-phase.

In either of the transducers of Figures 8 and 9, the piezo-electric sensing element can be positioned in any convenient location within the tines or yoke where it will be flexed by, and thus sense, the vibrations of the tines. Further, these transducers can all incorporate vibration isolation means of the form shown in Figure 9, comprising a frusto-conical

member 849 having its base welded to the top of the yoke and its narrower end secured, for example, in a flange member (or very short pipe section) adapted to be connected in flow series in a conduit carrying the fluid in which the transducer is to be immersed.

It will be appreciated that the transducers of Figures 8 and 9 both have appropriate passages for making electrical connections to the piezo-electric exciting and sensing means from the tops of their respective yokes: however, these passages have all been omitted in Figures 8 and 9, for the sake of simplicity.

## Claims

1. A fluid transducer comprising:
  - a sensing element (10) adapted for immersion in a fluid, said sensing element comprising a pair of tines (834, 835; or 845, 846) which extend in an axial direction from and are coupled together by a common yoke (836 or 842) and which are resonantly vibratable at a common frequency but in antiphase;
    - piezoelectric means (830; or 840, 841) mounted within the sensing element for exciting such resonant antiphase vibration of the tines; and
      - further piezoelectric means (20 or 48) mounted within the sensing element for sensing the frequency of the vibration;
        - characterised in that the exciting means (830; or 840, 841) is mounted under axial compression in a cavity (831; or 850, 851) in the yoke (836 or 842) in a region thereof closely adjacent the point where the inner face (832 or 833; or 843 or 844) of one of the tines (834 or 835; or 845 or 846) joins the yoke.
2. A transducer as claimed in claim 1, characterised in that the exciting means (830; or 840, 841) is arranged to provide continuous excitation.
3. A transducer as claimed in claim 1 or claim 2, characterised in that said cavity (831) is symmetrically positioned in said yoke with respect to the tines.
4. A transducer as claimed in any preceding claim, further characterised by a shroud (103) surrounding the sensing element (10).
5. A transducer as claimed in any preceding claim, further characterised by mounting means (15) for mounting the sensing element for immersion in the fluid, and vibration isolation means (16 or 849) for isolating the sensing

element (10) from the mounting means.

6. A transducer as claimed in claim 5, characterised in that the vibration isolation means comprises a bellows (16).
7. A transducer as claimed in claim 5, characterised in that the vibration isolation means comprises a frusto-conical member (849) having its base secured to said common yoke (842) and its narrower end secured to said mounting means (15).
8. A transducer as claimed in any preceding claim, characterised in that each tine (12, 14) has a re-entrant surface (21, 22) facing in the direction of vibration, whereby to enhance the sensitivity of the sensing element to fluid density.
9. A transducer as claimed in any of claims 1 to 7, characterised in that each tine (60, 61) has a generally elliptical cross-section, with the major axis of its elliptical section extending in the direction of vibration of the tine, whereby to enhance the sensitivity of the sensing element to fluid viscosity.

#### Patentansprüche

1. Ein Fluidwandler, umfassend:  
 ein Sensorelement (10), ausgebildet für das Eintauchen in ein Fluid, welches Sensorelement ein Paar von Zinken (834, 835; oder 845, 846) umfaßt, die sich in einer Axialrichtung von einem gemeinsamen Joch (836 oder 842) erstrecken und über dieses miteinander gekoppelt sind, und die zu Resonanzschwingungen bei einer gleichen Frequenz, jedoch in Gegenphase, anregbar sind;  
 piezoelektrische Mittel (830; oder 840, 841), die innerhalb des Sensorelementes montiert sind für die Erregung solcher resonanter gegenphasiger Vibrationen der Zinken; und  
 weitere piezoelektrische Mittel (20 oder 48), die innerhalb des Sensorelementes montiert sind für die Erfassung der Vibrationsfrequenz;  
 dadurch gekennzeichnet, daß die Erregungsmittel (830; oder 840, 841) unter axialer Kompression in einem Hohlraum (831; oder 850, 851) in dem Joch (836 oder 842) in einem Bereich desselben dicht an dem Punkt montiert sind, wo die innere Seite (832 oder 833; oder 843 oder 844) einer der Zinken (834 oder 835; oder 845 oder 846) auf das Joch trifft.

2. Ein Wandler nach Anspruch 1, dadurch gekennzeichnet, daß die Erregungsmittel (830; oder 840, 841) für die Bereitstellung einer kontinuierlichen Erregung ausgebildet sind.

3. Ein Wandler nach Anspruch 1 oder Anspruch 2, dadurch gekennzeichnet, daß der Hohlraum (831) symmetrisch in dem Joch bezüglich der Zinken positioniert ist.

4. Ein Wandler nach einem der vorangehenden Ansprüche, ferner gekennzeichnet durch eine das Sensorelement (10) umgebende Schutzhülse (103).

5. Ein Wandler nach einem der vorangehenden Ansprüche, ferner gekennzeichnet durch Montagemittel (15) für das Montieren des Sensorelements für das Eintauchen in das Fluid, und durch Vibrationsisolationsmittel (16 oder 849) für das Isolieren des Sensorelements (10) von den Montagemitteln.

6. Ein Wandler nach Anspruch 5, dadurch gekennzeichnet, daß die Vibrationsisolationsmittel einen Balgen (16) umfassen.

7. Ein Wandler nach Anspruch 5, dadurch gekennzeichnet, daß die Vibrationsisolationsmittel ein Kegelstumpfglied (849) umfassen, das mit seiner Basis an dem gemeinsamen Joch (842) und mit seinem schmaleren Ende an den Montagemitteln (15) befestigt ist.

8. Ein Wandler nach einem der vorangehenden Ansprüche, dadurch gekennzeichnet, daß jeder Zinken (12, 14) eine Wiedereintrittsoberfläche (21, 22) aufweist, die in der Vibrationsrichtung gekehrt ist, wodurch die Empfindlichkeit des Sensorelements gegenüber der Fluidichte gesteigert wird.

9. Ein Wandler nach einem der Ansprüche 1 bis 7, dadurch gekennzeichnet, daß jede Zinke (60, 61) einen generell elliptischen Querschnitt aufweist, wobei die Hauptachse des elliptischen Querschnitts sich in der Vibrationsrichtung der Zinke erstreckt, wodurch die Empfindlichkeit des Sensorelements gegenüber der Fluidviskosität erhöht wird.

#### Revendications

1. Transducteur pour fluide comprenant :  
 un élément détecteur (10) adapté à être plongé dans un fluide, ledit élément détecteur comprenant une paire de dents (834, 835; ou 845, 846) qui s'étendent dans une direction

axiale à partir de, et en étant reliées ensemble par, un étrier commun (836 ou 842), et qui peuvent être mis en vibration par résonance à une fréquence commune mais en opposition de phase;

un moyen piézoélectrique (830; ou 840, 841) monté à l'intérieur dudit élément détecteur pour exciter cette vibration résonnante des dents en opposition de phase; et

un autre moyen piézoélectrique (20 ou 48) monté à l'intérieur dudit élément détecteur pour détecter la fréquence de la vibration;

caractérisé en ce que le moyen d'excitation (830; ou 840, 841) est monté sous compression axiale dans une cavité (831; ou 850, 851) dans l'étrier (836 ou 842) dans une région de ce dernier faiblement espacée du point où la face intérieure (832 ou 833; ou 843 ou 844) de l'une des dents (834 ou 835; ou 845 ou 846) rejoint l'étrier.

2. Transducteur selon la revendication 1, caractérisé en ce que le moyen d'excitation (830; ou 840, 841) est adapté à fournir une excitation continue.

3. Transducteur selon la revendication 1 ou la revendication 2, caractérisé en ce que ladite cavité (831) est disposée symétriquement dans ledit étrier par rapport aux dents.

4. Transducteur selon l'une quelconque des revendications précédentes, caractérisé en outre par une enveloppe (103) entourant l'élément détecteur (10).

5. Transducteur selon l'une quelconque des revendications précédentes, caractérisé en outre par un moyen de montage (15) pour monter l'élément détecteur afin de le plonger dans le fluide, et un moyen d'isolation contre les vibrations (16 ou 849) pour isoler l'élément détecteur (10) du moyen de montage.

6. Transducteur selon la revendication 5, caractérisé en ce que le moyen d'isolation contre les vibrations comprend un soufflet (16).

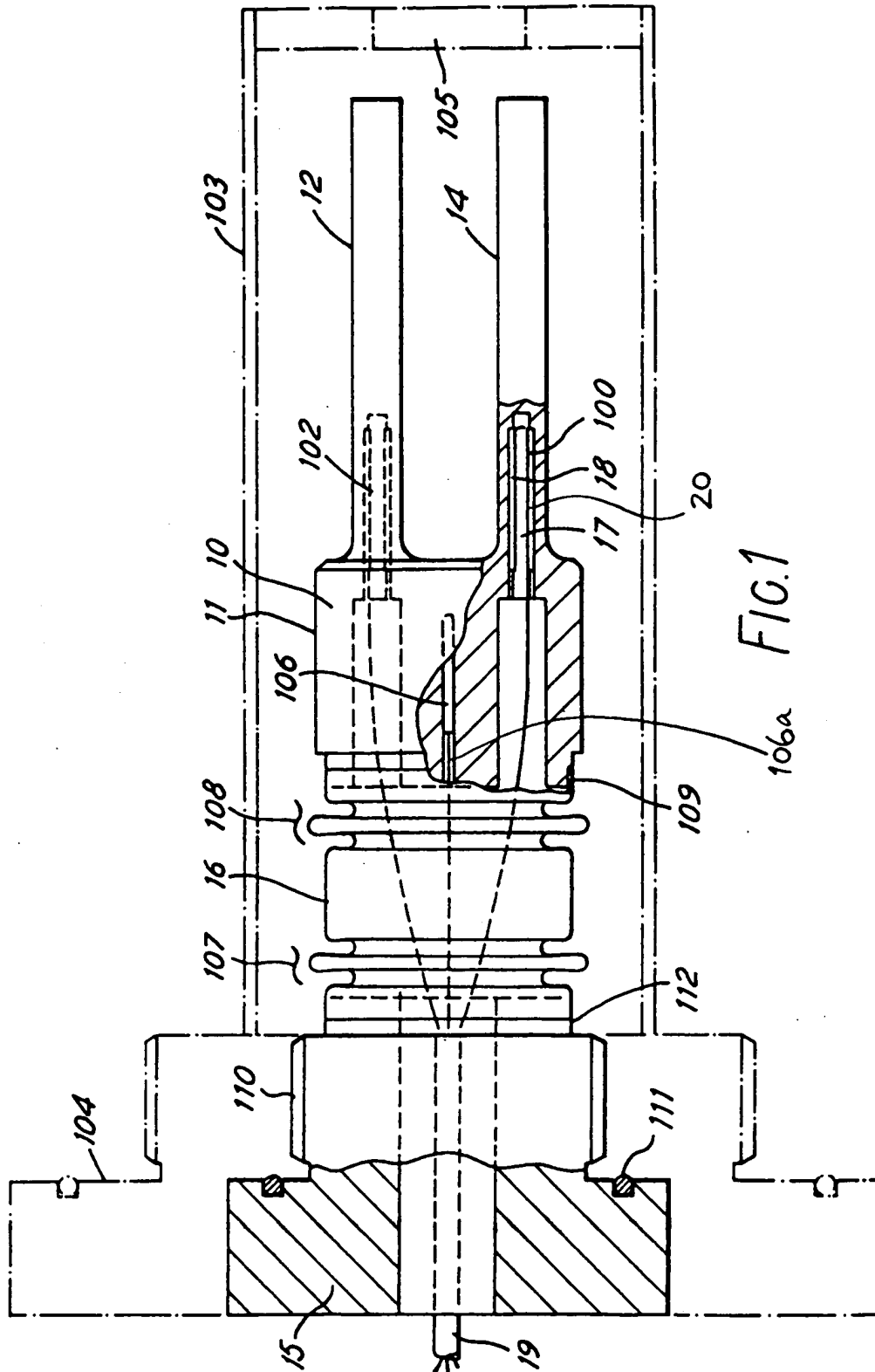
7. Transducteur selon la revendication 5, caractérisé en ce que le moyen d'isolation contre les vibrations comprend un élément tronconique (849) dont la base est fixée audit étrier commun (842) et l'extrémité étroite est fixée audit moyen de montage (15).

8. Transducteur selon l'une quelconque des revendications précédentes, caractérisé en ce que chaque dent (12,14) présente une surface

rentrante (21,22) orientée dans la direction des vibrations, de façon à accroître la sensibilité de l'élément détecteur à la densité du fluide.

9. Transducteur selon l'une quelconque des revendications 1 à 7, caractérisé en ce que chaque dent (60,61) présente une section transversale globalement elliptique, le grand axe de sa section elliptique s'étendant dans la direction des vibrations de la dent, afin d'accroître la sensibilité de l'élément détecteur à la viscosité du fluide.





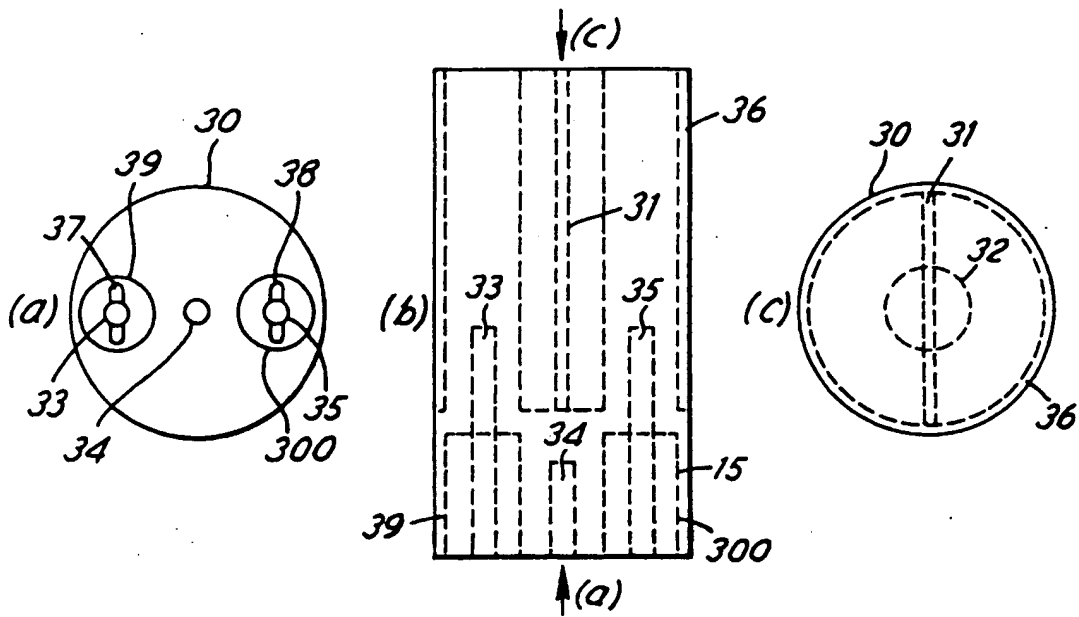
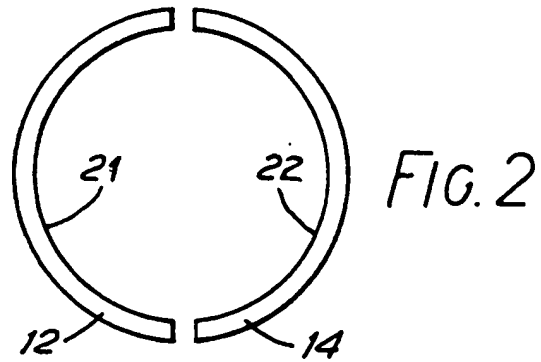
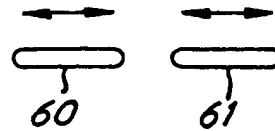
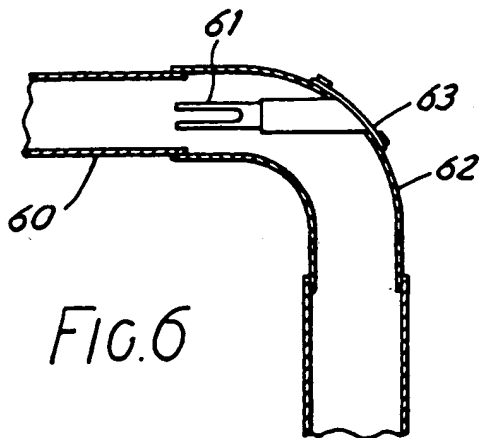
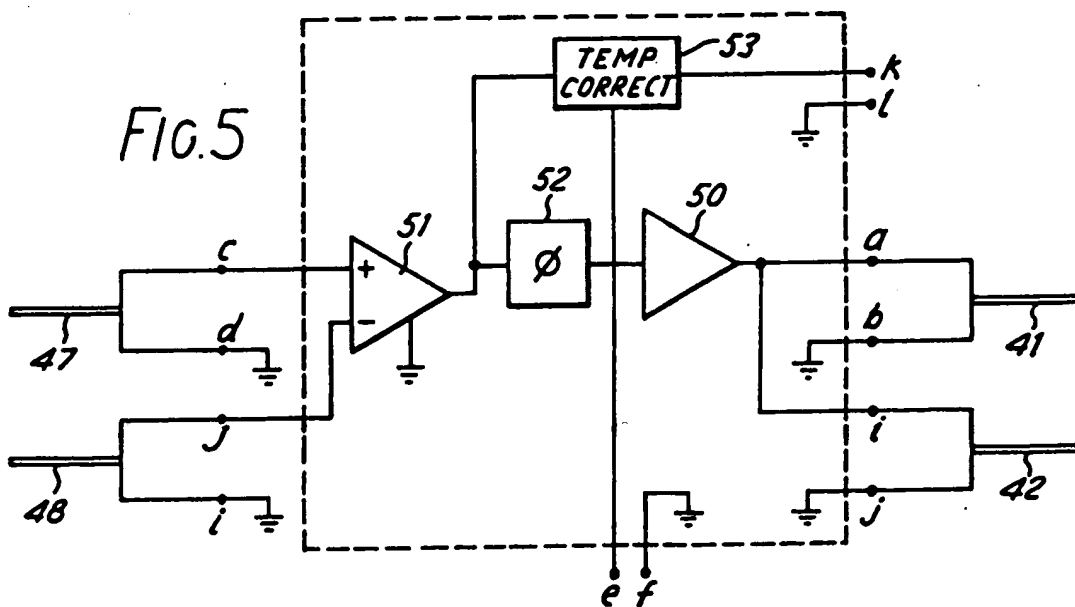
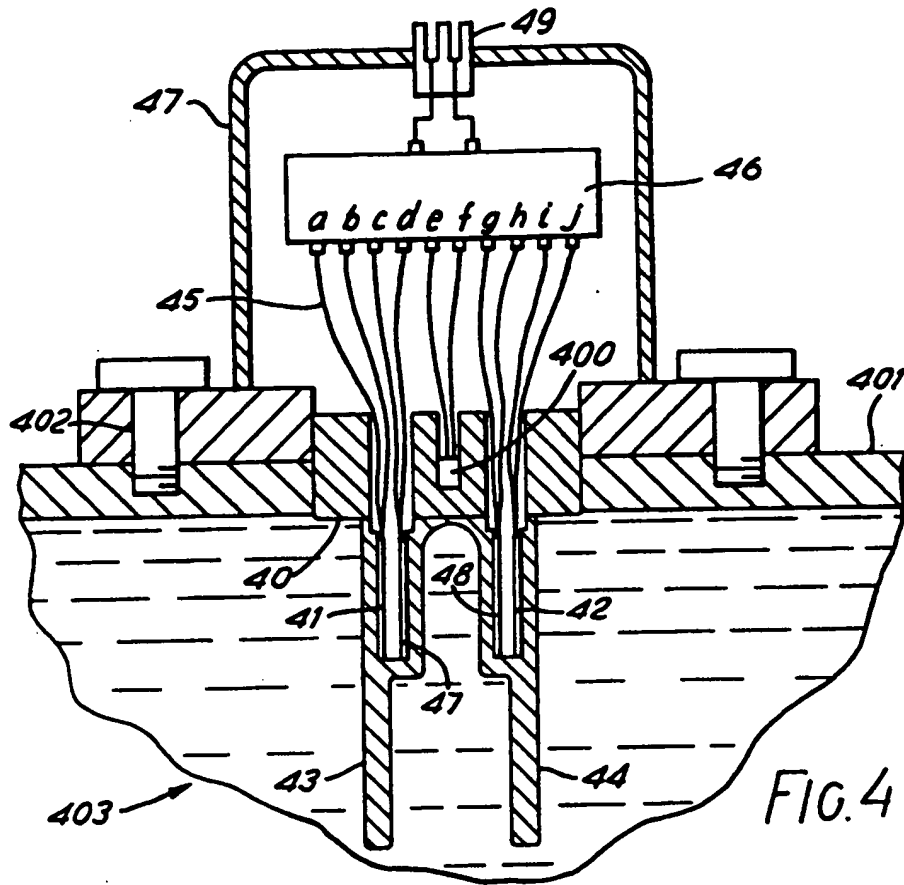


FIG. 3





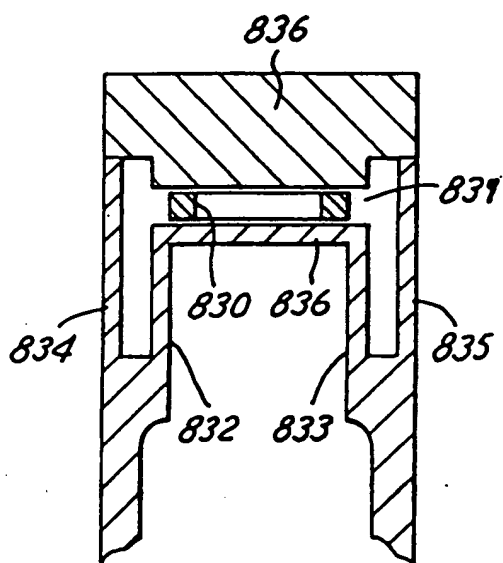


FIG 8

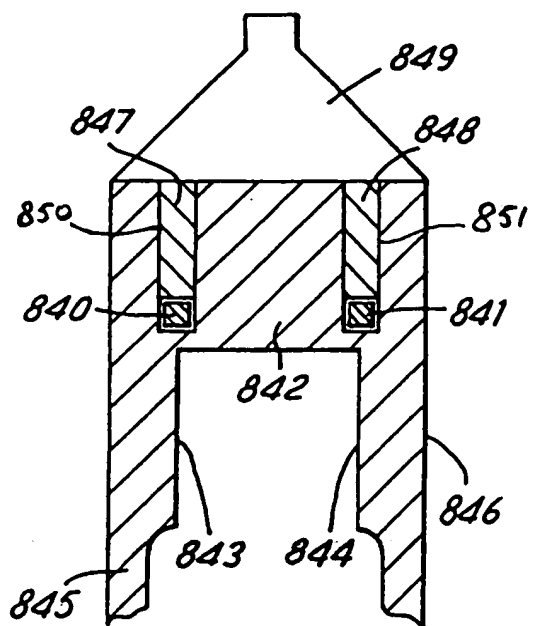


FIG 9

**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

☒ **BLACK BORDERS**

☐ **IMAGE CUT OFF AT TOP, BOTTOM OR SIDES**

☐ **FADED TEXT OR DRAWING**

☒ **BLURRED OR ILLEGIBLE TEXT OR DRAWING**

☐ **SKEWED/SLANTED IMAGES**

☐ **COLOR OR BLACK AND WHITE PHOTOGRAPHS**

☐ **GRAY SCALE DOCUMENTS**

☐ **LINES OR MARKS ON ORIGINAL DOCUMENT**

☐ **REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY**

☐ **OTHER:** \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**